3.20 Antenna Gain Validation

Summary of Results

Antenna gain can impact target detection range in a stand-off jamming environment. It is recommended that a 3-D measured antenna gain pattern, rather than a pattern built by ALARM from a 2-D pattern, be used in studies involving stand-off jamming.

Functional Element Description

The overall function of the antenna is to directionally radiate radar signals and to directionally receive target/clutter/jamming reflected radar signals. The gain of an antenna has a significant impact on radar target detection and tracking performance. Although the antenna gain, near the antenna boresight, has the greatest impact upon radar performance, the off-boresight or side-lobe antenna gain influences the effects of clutter, ECM, and multipath on both target detection and tracking. In radar modeling, it is essential to accurately represent the three dimensional gain of the antenna at both boresight and off-boresight positions.

The antenna function is modeled as antenna gain, relative to an omnidirectional antenna, as a function of viewing angle off-boresight. The modeled antenna gain pattern and antenna gain resolution are critical subfunctions for a valid radar antenna model.

Antenna gain is often modeled by a mathematical function such as the one shown in equation (3.20-1), which describes a uniform (rectangular) aperture distribution:

$$G(\theta) = \left(\frac{\sin k\theta}{k\theta}\right)^2$$

$$k = \frac{2.7831148}{\theta_b} \qquad (3.20\text{-}1)$$

where θ = angle, in radians, off-boresight
θ_b = beamwidth

Gain is also modeled as an input table having measured gain values for off-boresight angular increments over orthogonal azimuth and elevation planes.

In ALARM, the user has the option of specifying either a three-dimensional antenna pattern generated by the model from two-dimensional orthogonal slices in azimuth and elevation through the antenna boresight, or a full three-dimensional digitized gain pattern. For either type of pattern, the model requires input elevation and azimuth antenna gain values at increments specified by the user, but limited by model dimensions to 0.1˚ steps (or greater). The antenna gain in a particular direction is determined by finding the off-boresight azimuth and elevation angles of the random point in space of interest. This point may represent the target, a terrain patch, or a stand-off jammer. For a 3-D gain pattern, a simple look-up in the array containing the pattern yields the gain for the specified aspect. For a 2-D pattern, the user-supplied azimuth plane and elevation plane contributions to the off-boresight gain are determined as a function of the solid angle between the azimuth and elevation look-up angles and the root sum of squares value of the azimuth and elevation look-up angles. These contributions are then linearly interpolated to determine the off-boresight gain.

3.20.1 Comparison of Measured and Modeled 3-D Antenna Gain Patterns

Validation Objective: Visually compare actual 3-D antenna gain patterns with those generated by ALARM from 2-D orthogonal gain cuts from the measured data in order to determine how closely the generated pattern matches the actual pattern.

Test Description: A classified test of target track, acquisition, and missile track radar antennas was conducted by Georgia Tech Research Institute (GTRI) in 1992. Results of this data collection effort are described in *Final Report - XM08-23 Antenna Testing* [A.2-18]. The collected test data have been retained by GTRI and can be made available to authorized users.

The antenna data were collected by removing the antennas from the system under test, mounting them on a tower at a far-field test range, and measuring the primary parameters associated with the directivity and transmission networks of the antenna assemblies. The antenna of interest in validating ALARM antenna gain was that used in the target tracking system of the test article. The data measured for this antenna included return and insertion loss of the multiplexor, antenna directivity patterns, and measurements to determine cross polarization performance.

Data were obtained by connecting the antenna to a calibrated receiver capable of measuring the power received at both sum and difference antenna ports. A source antenna nulling network was used to obtain cross-polarization measurements. The nulling network consisted of a dual-polarized transmit antenna connected to a power divider network which controlled the amplitude and phase of the excitation ports of the dual polarized antenna. The source antenna and nulling network were used to match the co- and cross-polarization ellipses of the antenna under test. The alignment of the network was performed at the boresight of the sum (Σ) pattern to achieve a maximum null depth in amplitude. The network was then switched to provide the co-polarized excitation. The power divider in the nulling network was used to simulate a rotating linear source for axial ratio measurements.

The antenna was mounted on a pedestal; the upper azimuth turntable (which yielded concial cuts) was used for all pattern cuts. The fixture supporting the antenna on the pedestal allowed the antenna to be positioned for elevation or azimuth patterns. All tests were performed with the antenna receiving and at low RF power.

Data Description: The data of interest in validating ALARM were the sum channel, co-polarized antenna patterns, measured in 0.2˚ increments over ±15.0˚ azimuth cuts and ±15.0˚ elevation cuts, using a frequency of 14.875 GHz.

Data Processing: No special processing of the data was required. The data were sent in ASCII files containing antenna gain values at the azimuth/elevation locations listed above.

Analysis Procedures: ALARM's antenna pattern generation subroutines were run with an off-line driver, and modified to output the generated 3-D pattern. The input to the pattern generator came from two orthogonal cuts from the measured data; the cuts were through the 0˚ azimuth plane and 0˚ elevation plane. The modeled 3-D pattern was visually compared with the measured pattern. Further comparisons were made by creating 2-D graphs of the gain patterns lying in the plane that passes through the boresight at a 45˚ angle from zero azimuth and in the plane that passes through the boresight at a 45˚ angle from zero elevation.

Results and Interpretation: The 3-D measured antenna gain pattern is shown in Figure 3.20-1. The 3-D modeled antenna gain pattern, derived using 2-D gain parameters, is shown in Figure 3.20-2. The differences in the two antenna gain patterns are depicted in Figure 3.20-3. This figure compares a diagonal slice, from approximately (–13.0˚ azimuth, –13.0˚ elevation) to (+13.0˚ azimuth, +13.0˚ elevation), of the modeled and measured antenna gain patterns. The patterns show a near-perfect match for on-boresight conditions with some differences at off-boresight angles.

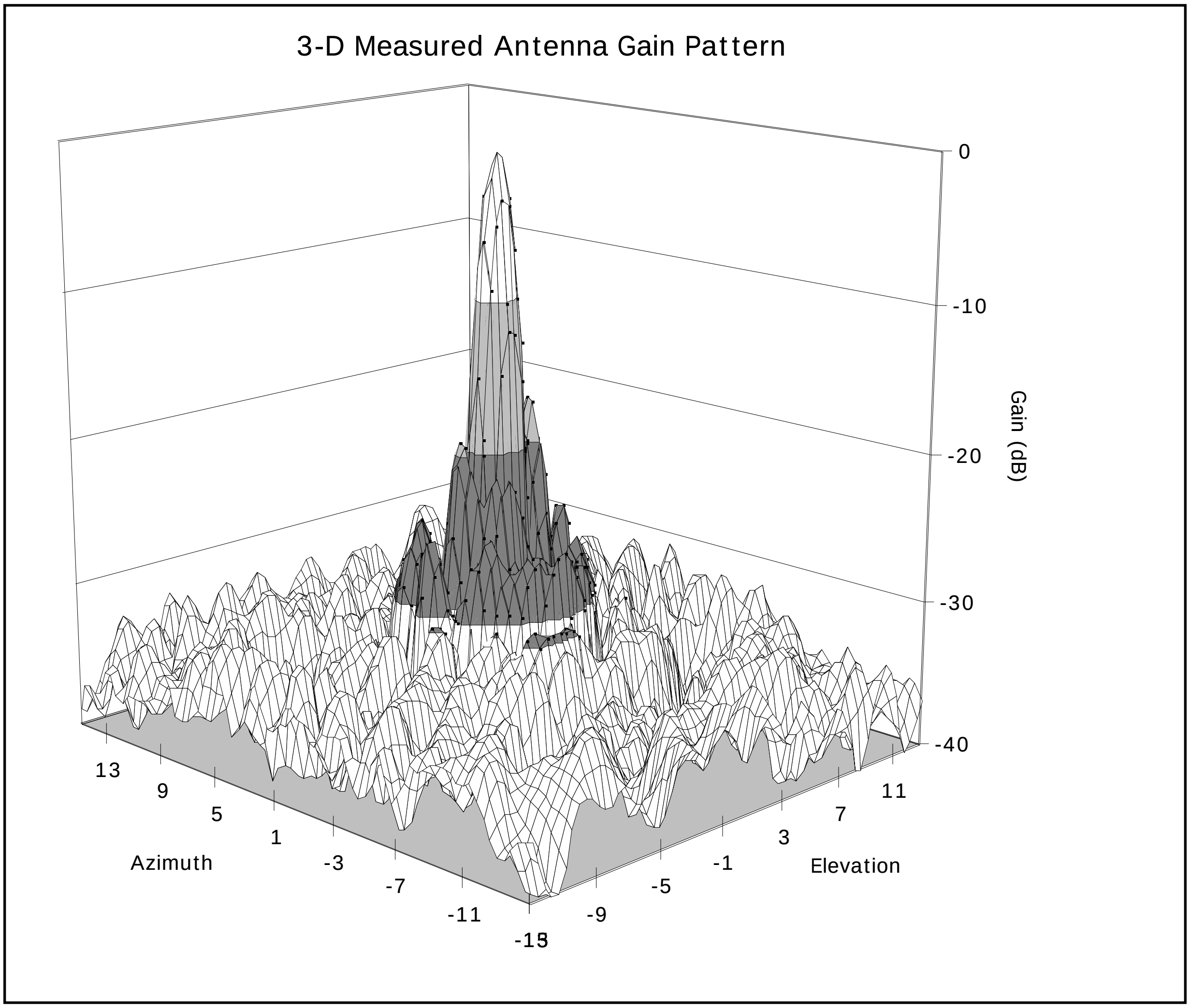

Figure 3.20-1 Measured 3-D Antenna Gain

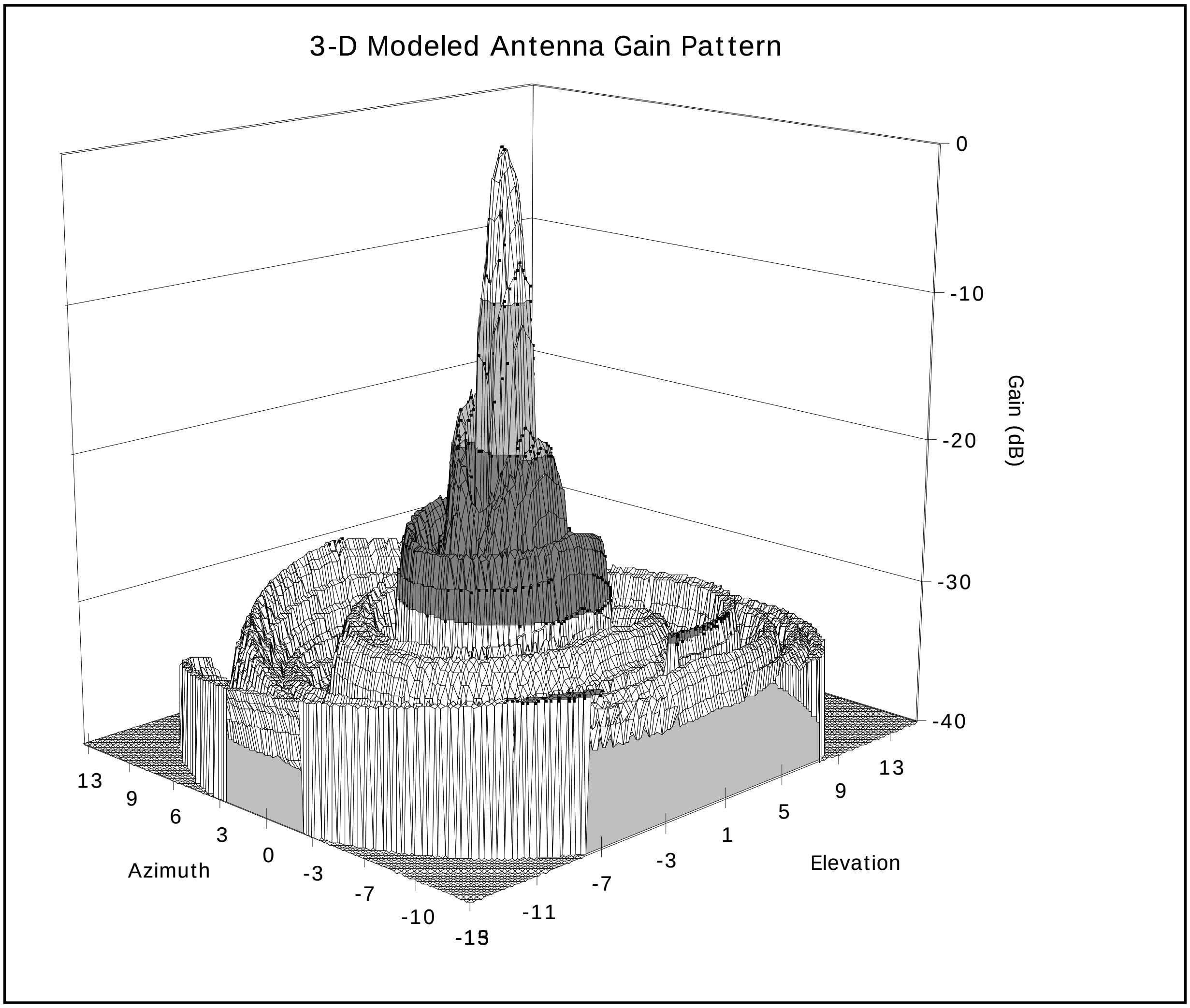

Figure 3.20-2 Modeled 3-D Antenna Gain

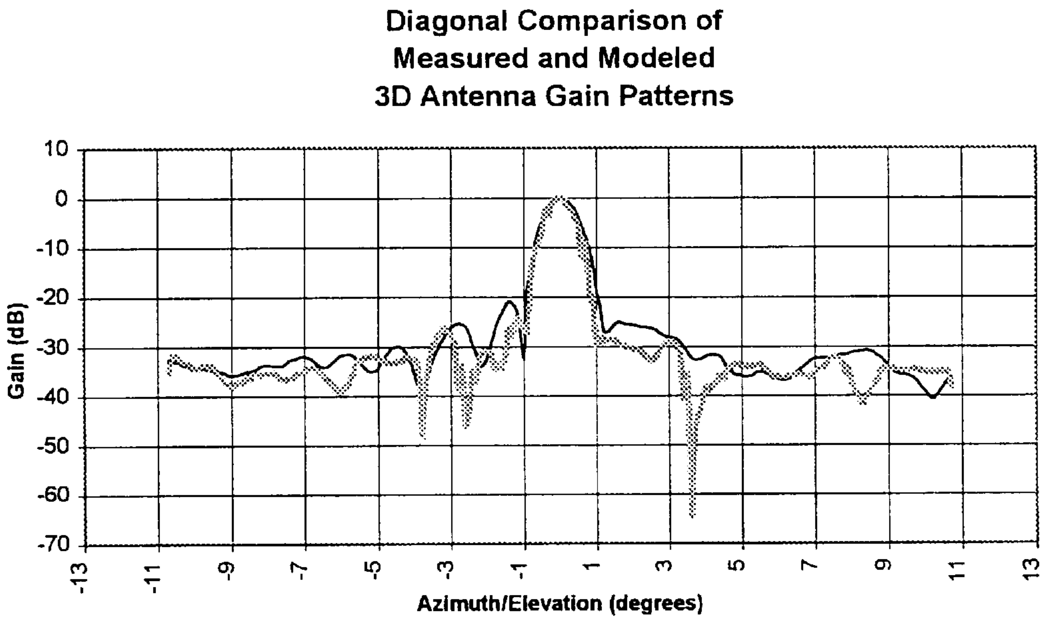

Figure 3.20-3 Diagonal Comparison of Modeled and Measured 3-D Antenna Gain

Conclusions: Depending upon the fidelity requirements of a particular study, off-boresight effects such as side-lobe jamming and clutter may not be validly represented using 3-D patterns derived from 2-D data. Further testing is required to ascertain the impact of off-boresight differences.

3.20.2 Effects of Stand-Off Jamming on Antenna Gain

Validation Objective: Determine the impact of using a 3-D modeled antenna gain pattern, rather than an actual 3-D gain pattern, in a stand-off jamming (SOJ) environment.

Measures of Effectiveness: One MOE was selected for this test, the range from the radar to the target at time of detection.

Test Description: Data from the classified test described in Section 3.20.1 were used in the validation testing of the effect of stand-off jamming on antenna gain patterns.

Data Description: The same data, as described in Section 3.20.1, were used in the conduct of this test.

Data Processing: No special processing of the data was required for this test.

Analysis Procedures: Two ALARM runs were made, using a stand-off jammer. The jammer was located in the modeled scenario such that it would produce its greatest effect in the sidelobes of the antenna. The relevant input values for the jammer are given in Table 3.20-1. The values for jammer power and antenna gain were chosen in order to simulate a nominal stand-off jammer. ALARM was executed in Contour Plot mode for both runs. For the first run, the modeled 3-D antenna pattern was used. For the second run, the actual 3-D pattern was input. All other inputs were identical to the baseline parameters identified in Appendix B.

The initial target detection range output from both runs was compared to ascertain the impact of using modeled 3-D patterns vs. measured 3-D patterns in a stand-off jamming environment. The analysis methodology was the same as that described in Section 3.0 of ASP II for normalized mean difference statistical analysis.

Table 3.20-1 ALARM Input Data Set for Nominal Stand-Off Jammer

Record	Variable	Value	Description
0	DATABLK	DATAGANT	Radar transmit antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZTXD	0.2	Transmitter gain pattern azimuth increment
	DELTXD	0.2	Transmitter gain pattern elevation increment
0	DATABLK	DATAGANR	Radar receive antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZRXD	0.2	Receiver gain pattern azimuth increment
	DELRXD	0.2	Receiver gain pattern elevation increment

Table 3.20-1 ALARM Input Data Set for Nominal Stand-Off Jammer

Record	Variable	Value	Description
0	DATABLK	DATAJAMR	Engineering-level jammer data
	FILNAM		Input file containing jammer data; not used for this test
1	IPRJAM	1	Print control variable - echo input to output file
	JAMTYP	2	Jammer type = stand-off noise jammer
	NUMSOJ	1	Number of stand-off jammers
2	PWRJAM	1000.0 kW	Jammer power
	GJAMDB	0.0 dB	Jammer antenna gain
	BWJAMR	6.0 MHz	Jammer bandwidth (matches radar noise bandwidth)
	DBLOSJ	0 dB	Jammer power transmission loss
	CFREQJ	14875.0 MHz	Jammer center transmission frequency (matches radar frequency)
	DBJTOS	Not Used	Effectiveness Threshold (JAMTYP=1 or 4 only)
3	LADSOJ	30°	SOJ latitude degrees
	LAMSOJ	29'	SOJ latitude minutes
	LASSOJ	45"	SOJ latitude seconds
	LODSOJ	–86°	SOJ longitude degrees
	LOMSOJ	44'	SOJ longitude minutes
	LOSSOJ	30"	SOJ longitude seconds
	ZSOJM	15,240.0 m	SOJ altitude
	MSLSOJ	1	SOJ altitude is MSL

Results and Interpretation: Figure 3.20-4 depicts the effect on initial target detection range of a stand-off jammer within an effective jamming range. For the majority of the detection plot, the two cases are very close. The plots diverge around –15 km offset from the radar site. This is due to the effect of the stand-off jammer at that position.

The statistics, displayed in Table 3.20-2, show little difference between the two plots when taken as a whole. However, an examination of the statistics associated with the area affected by the stand-off jammer (–20 km to –14 km offset) shows significant differences. The normalized statistic indicates an approximate 20% difference.

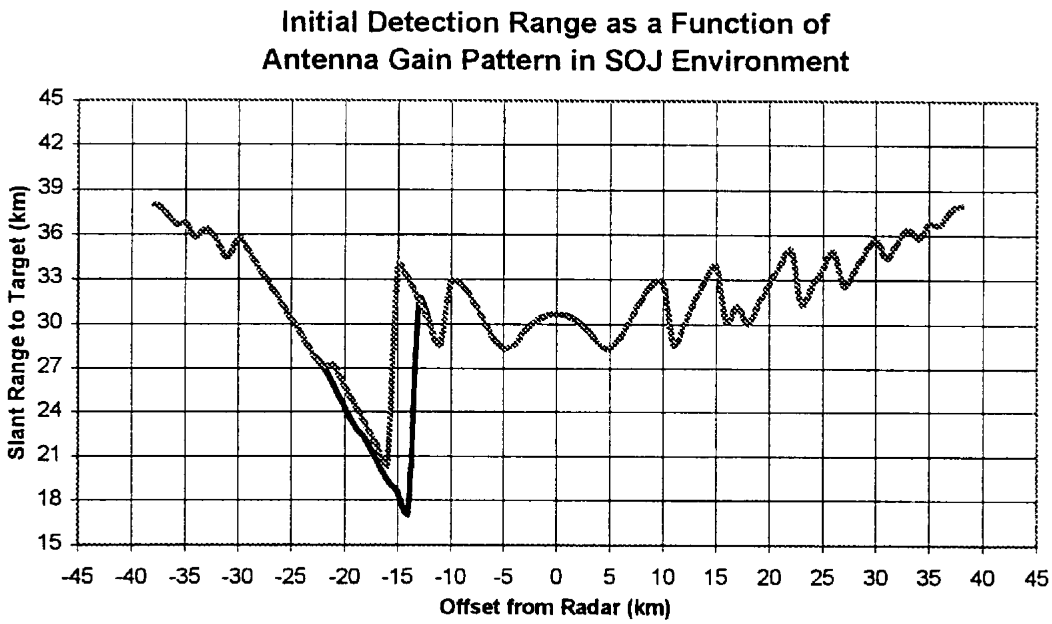

Figure 3.20-4 Modeled and Measured 3-D Antenna Gain in a Stand-off Jamming Environment

Table 3.20-2 Detection Range Variance as a Function of Modeled and Measured 3-D Antenna Gain Patterns in a Stand-Off Jamming Environment

Case	Mean (m)	σ (m)	Normalized Mean Difference	%Change
Measured Antenna Gain	31.38	4.49	-	-
Modeled Antenna Gain	31.88	3.70	-0.008	-1.55
Measured Antenna Gain (–20 km to –14 km Offset)	20.76	2.55	-	-
Modeled Antenna Gain (–20 km to –14 km Offset)	26.04	5.31	-0.113	-20.28

Conclusions: The impact of modeling 3-D antenna gain patterns versus use of actual 3-D patterns is significant in the area where stand-off jamming is present. The user of ALARM should exercise caution when applying ALARM to studies involving stand-off jamming; where possible, actual 3-D antenna patterns should be utilized.

3.20.3 Effects of Clutter on Antenna Gain Patterns

Validation Objective: Determine the impact of using modeled 3-D antenna gain patterns, rather than actual gain patterns, in a high-clutter environment.

Measures of Effectiveness: One MOE was selected for this test, the range from the radar to the target at time of detection.

Test Description: Data from the classified test described in Section 3.20.1 were used in the validation testing of the effect of clutter on antenna gain patterns.

Data Description: The same data, as described in Section 3.20.1, were used in the conduct of this test.

Data Processing: No special processing of the data was required for this test.

Analysis Procedures: Two ALARM runs were made, using a clutter environment. The input to ALARM to create the clutter environment included actual DMA data and a large azimuth increment, which causes an increase in the size of the clutter patch evaluated during the model run. The relevant input values for the clutter runs are given in Table 3.20-3. Note that this input effectively fixes the antenna elevation to zero; this was necessary because the clutter in the scenario was greatest at this elevation angle. For both model runs, ALARM was executed in Contour Plot mode. For the first run, the modeled 3-D antenna pattern was used. For the second run, the actual 3-D pattern was input. All other inputs were identical to the baseline parameters identified in Appendix B. The initial target detection range output from both runs was compared to ascertain the impact of using modeled 3-D patterns vs. measured 3-D patterns in a clutter environment. The analysis methodology was the same as that described in Section 3.0 of ASP II for normalized mean difference statistical analysis.

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Table 3.20-3 ALARM Input Data Set for Clutter Environment

Record	Variable	Value	Description
0	DATABLK	DATAGANT	Radar transmit antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZTXD	0.2	Transmitter gain pattern azimuth increment
	DELTXD	0.2	Transmitter gain pattern elevation increment
0	DATABLK	DATAGANR	Radar receive antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZRXD	0.2	Receiver gain pattern azimuth increment
	DELRXD	0.2	Receiver gain pattern elevation increment

Table 3.20-3 ALARM Input Data Set for Clutter Environment

Record	Variable	Value	Description
0	DATABLK	DATARADR	Engineering-level radar data
4	ELMIND	0.0°	Minimum elevation pointing angle (degrees)
	ELMAXD	0.0°	Maximum elevation pointing angle (degrees)
5	DAZCLD	0.1	Azimuth increment for computing clutter (degrees)
	AZOCLD	3.0	Maximum angle off-boresight for clutter (degrees)

Results and Interpretation: Figure 3.20-5 shows plots of target detection range using both modeled and measured 3-D antenna gain patterns, in a clutter environment. The two plots are indistinguishable.

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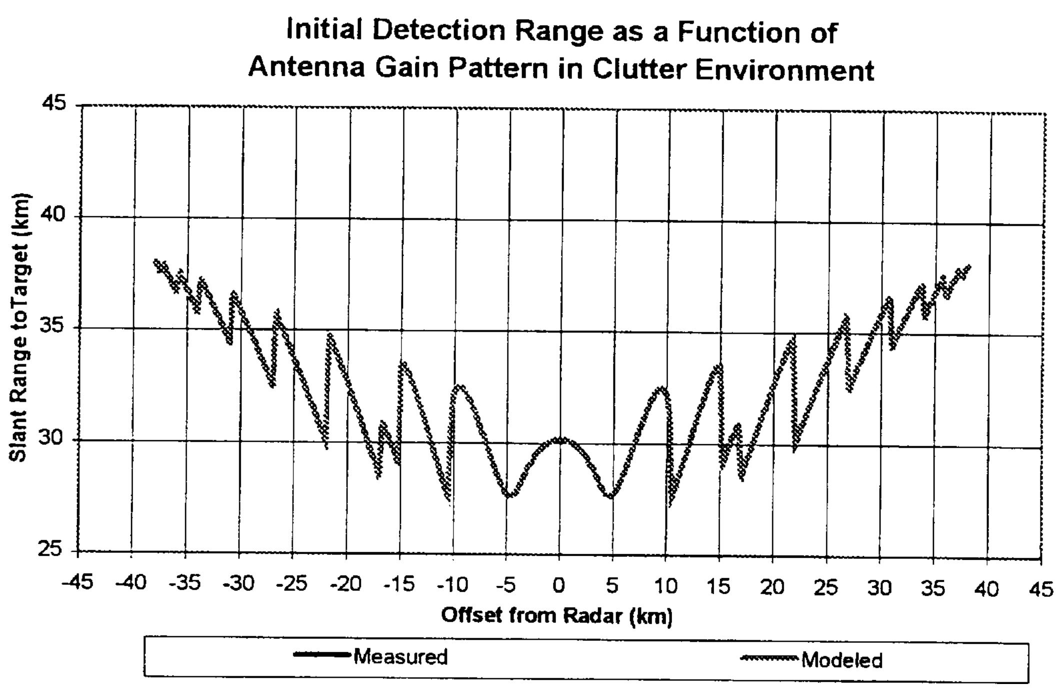

Figure 3.20-5 Modeled and Measured 3-D Antenna Gain in a Clutter Environment (Antenna Elevation Fixed at 0.0˚)

Conclusions: Based on the results of the model runs as indicated by the plots in Figure 3.20-5, there are no differences in detection range between the two radar antenna patterns in a clutter environment. The user of ALARM can choose between modeled or actual 3-D antenna patterns in studies involving clutter.

3.20.4 Antenna Gain Without Stand-Off Jamming or Clutter

Validation Objective: Determine the impact on predicted target detection range of using modeled 3-D antenna gain, rather than measured 3-D antenna gain, in a non-jamming, low clutter environment.

Test Description: Data from the classified test described in Section 3.20.1 were used in the comparison of modeled and measured 3-D antenna gain patterns, in the absence of jammers and clutter.

Data Description: The same data, as described in Section 3.20.1, were used in the conduct of this test.

Data Processing: No special processing of the data was required for this test.

Analysis Procedures: Two ALARM runs were made, using neither clutter nor stand-off jamming. The input to ALARM to turn off clutter is shown in Table 3.20-5. Side-lobe jamming was bypassed by not including the data given in Table 3.20-1 in the model runs. ALARM was executed in Contour Plot mode for both runs. For the first run, the modeled 3-D antenna pattern was used. For the second run, the actual 3-D pattern was input. All other inputs were identical to the baseline parameters identified in Appendix B.

The initial target detection range output from both runs was compared to ascertain the impact of using modeled 3-D patterns vs. measured 3-D patterns in a low clutter, non-jamming environment. The analysis methodology was the same as that described in section 3.0 of ASP II for normalized mean difference statistical analysis.

Table 3.20-4 ALARM Input Data to Turn Off Clutter

Record	Variable	Value	Description
0	DATABLK	DATAGANT	Radar transmit antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZTXD	0.2	Transmitter gain pattern azimuth increment
	DELTXD	0.2	Transmitter gain pattern elevation increment
0	DATABLK	DATAGANR	Radar receive antenna pattern
	FILNAM	Not Used	Input file specifying antenna pattern
1	DAZRXD	0.2	Receiver gain pattern azimuth increment
	DELRXD	0.2	Receiver gain pattern elevation increment
0	DATABLK	DATARADR	Engineering-level radar data
5	AZOCLD	0.0°	Maximum angle off-boresight for clutter (since AZOCLD = 0, no clutter returns will be calculated)

Results and Interpretation: Figure 3.20-6 shows no difference in initial target detection range for the two model runs.

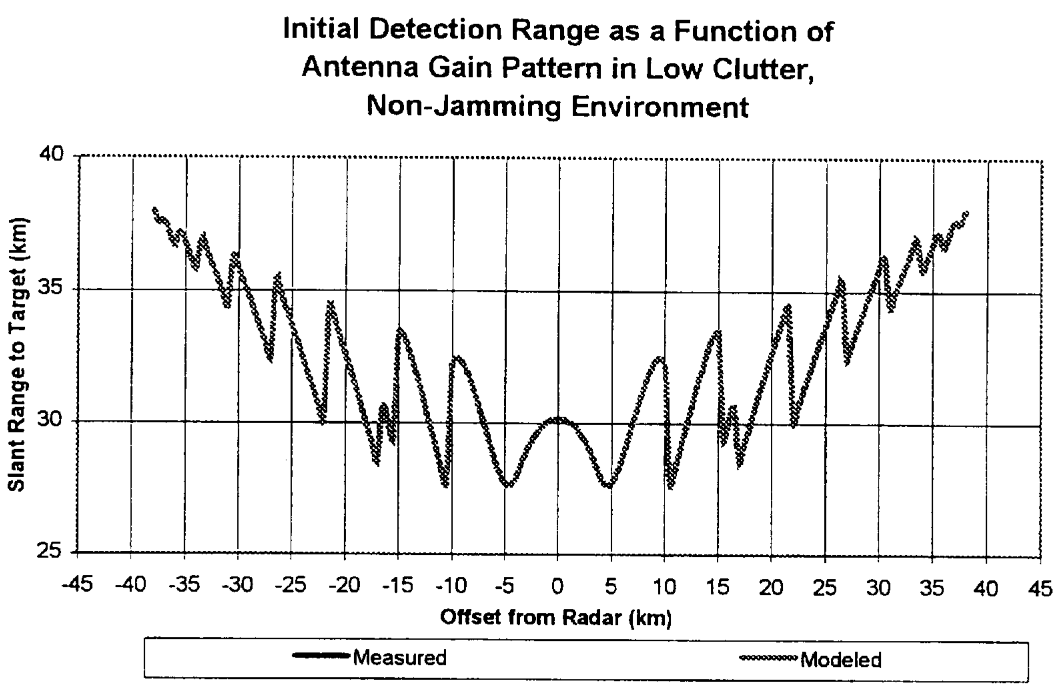

Figure 3.20-6 Modeled and Measured 3-D Antenna Gain Patterns
in a Non-Clutter and Non-Stand-Off Jamming Environment

Conclusions: The user of ALARM can choose between modeled and measured 3-D antenna patterns in studies that do not include clutter or stand-off jamming.